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A SUGGESTED PROGRAM OF ECLIPSE OBSERVATIONS FROM THE MOON

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PREFACE

This is a brief description of a proposed series of unique scientific experiments to be performed on the moon. The relative technical simplicity, yet high scientific value, make it ideally suitable as an early task for Apollo astronauts. Later program phases would provide for long-term extensions of the scientific program to manned missions in earth orbit and to manned flights between earth, moon, and the planets.

This suggestion was developed as part of the Apollo Contingency Planning Study being performed for the Director of Advanced Manned Missions in the Office of Manned Space Flight at NASA Headquarters under Contract NASr-21(09). It is intended to draw the attention of program planners to the potential advantages of adopting eclipse observations as one of the major scientific objectives of the Apollo and post-Apollo programs.

SUMMARY

Observations from the moon of eclipses of the sun and earth would present unique opportunities for performing valuable scientific experiments. They would be carried out most easily, efficiently, and economically by human observers with very simple instrumentation.

For the early Apollo missions, technical problems are minor, except for the necessity to time the missions around one to four favorable periods in each year. Concurrent, complementary scientific observations are here suggested for performance from the earth and from manned, earth-circling spacecraft.

Follow-on program phases are outlined in the context of subsequent lunar exploration and manned orbital laboratories, as well as for long-term scientific missions in cis-lunar and interplanetary space. This report discusses a progression of scientific objectives from the start of the suggested program, with the expected results to be obtained in solar physics, geophysics, astronomy, meteorology, and relativity theory.

Making eclipse observations one of the major scientific objectives of manned lunar exploration can be expected to receive support both from the scientific community and from the general public. The general public and amateur astronomers should be enlisted for active participation in simple eclipse observations, simultaneous with those of the lunar astronauts. Such an enlistment could be achieved through press and communications media, and governmental and scientific channels of international contact.

CONTENTS

I. INTRODUCTION

Eclipses of the moon and the sun have been observed and studied since ancient times. Hardly a human being has not had the opportunity of observing a lunar eclipse. The rarer but more awesome experience is that of a solar eclipse, with the moon slowly obscuring the sun until the whole landscape is bathed in dim twilight and the spectacular solar corona makes its appearance in the starry sky.

Observations of lunar and solar eclipses are enormously valuable for astronomy, astrophysics, and geophysics. Yet many worthwhile scientific experiments consist of simple filter photography or photometry -- even only of visual observations with precise timings.

The occurrence of observable lunar eclipses is quite frequent. But the observation of solar eclipses often requires special expeditions to the specific geographical area where one is visible, only to be frequently foiled by weather. The duration of totality of a solar eclipse is short. Even on board a high-speed jet aircraft chasing the fleeting earth's shadow above the clouds,[1] scientists have usually only a few minutes to perform their most important experiments.

In the following, we shall consider the unique opportunities resulting from the possibility of performing eclipse observations on the moon. The discussion will concentrate on the tasks which could be performed most easily and advantageously during the early Apollo flights, and will indicate some of the long-term aspects of a continuing eclipse observation program as part of manned spaceflight.

II. BASIC PRINCIPLES AND GEOMETRY

Astronomical eclipses occur when the light from a celestial body, such as the sun, is prevented by an intervening celestial body from reaching a third one and/or the observer. On earth, we are all familiar with both the lunar eclipse, where the moon passes through the earth's shadow, and the solar eclipse, where our view of the sun is obscured by the intervening moon. Other manifestations of this celestial phenomenon are the daily eclipses of artificial satellites in the earth's shadow, the occasional occultations of stars by planets, or the obscuration of radio stars by the moon, sun or solar corona.

The nature of an eclipse is dependent on the location of the observer. The difference in geometry is important and schematically illustrated in Fig. 1. On earth, lunar eclipses are generally visible to everyone over the entire hemisphere facing the moon. Solar eclipses, on the other hand, can only be seen by observers located within a narrow band corresponding to the path of the moon's shadow on the earth's surface.

Note from Fig. 1 that for an observer on the moon a "<u>SOLAR ECLIPSE</u>" occurs when we on earth are observing a lunar eclipse. Similarly, during a "<u>TERRESTRIAL ECLIPSE</u>" (really a transit or shadow crossing), a solar eclipse is observed on earth.* The earth being bigger than the moon, and because of their relative motions, an eclipse of the moon by the earth (observed on the moon as a SOLAR ECLIPSE) is quite an extensive phenomenon, both spatially and temporally. It will be visible for a relatively long time from all points of the lunar hemisphere at which the earth is above the horizon.

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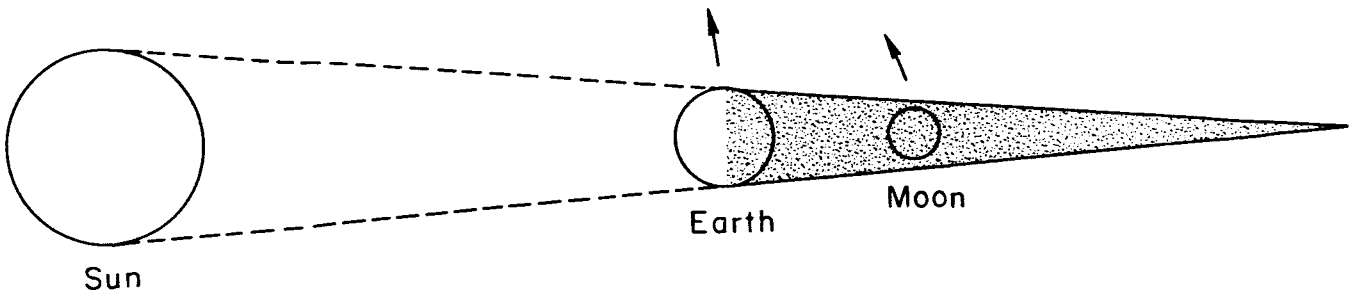
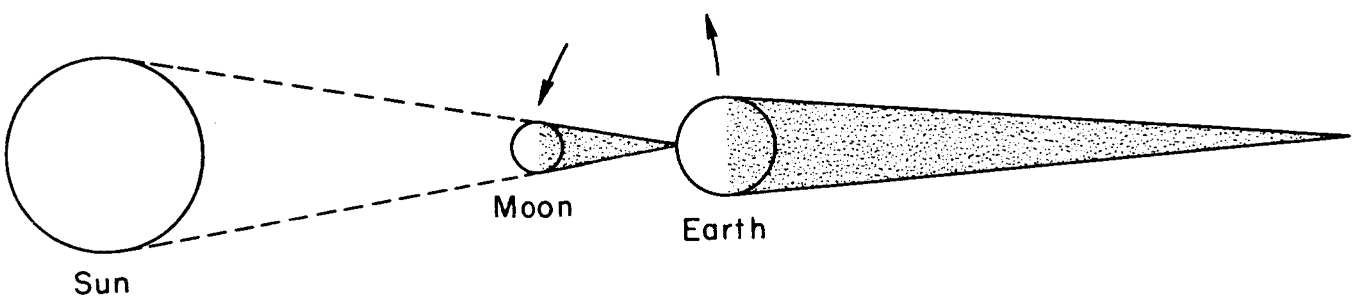
*Throughout this report, upper-case letters will refer to an eclipse viewed from the moon, lower-case to one viewed from the earth.

Full Moon Situation



Observer	Phenomenon
On Earth:	Lunar eclipse
On Moon:	SOLAR ECLIPSE

New Moon Situation



Observer	Phenomenon
On Earth:	Solar eclipse
On Moon:	TERRESTRIAL ECLIPSE

Fig. 1 —Schematic diagram of the celestial geometry of lunar and solar eclipses (not to scale)

III. SCIENTIFIC OBJECTIVES

INITIAL APOLLO PROGRAM

Solar Eclipses on Earth

The general scientific aims and objectives of eclipse research are well known.[2,3] Studies of solar eclipses are of fundamental value to solar physics and provide us with important information about the solar corona, the outermost region of the sun's atmosphere that extends into space for millions of miles.

The brightness of the sun makes this corona invisible under normal conditions. Solar physics has been greatly helped in recent years through the invention of the coronagraph, an instrument that artificially blocks out the solar disk and makes the rim visible. Nevertheless, the best data are obtained when it is the moon that blocks out the sun during an eclipse. Visual, photographic, spectroscopic, and radio-astronomy studies provide knowledge on the radial extent and shape of the corona, on its variations with solar cycle and sunspot activity, on streams of hot plasma which emanate from the lower layers of the solar atmosphere, and on the interaction between the corona and interplanetary space.

Precise astronomical photographs during a solar eclipse can also be used to investigate the Einstein shift, caused by the bending of starlight in the vicinity of the massive body of the sun.

Lunar Eclipses on Earth

Observations of lunar eclipses provide information about the earth's atmosphere not readily obtainable otherwise. The techniques primarily employed are those of visual photometry, photoelectric photometry, photographic photometry, and photographic spectrophotometry. The phenomena of shadow increase and shadow flattening can indicate variations about the temperature structure and the presence of absorbing layers high in the upper atmosphere.[4] The apparent brightness of the moon during an eclipse changes from year to year and is connected with the global weather situation on earth. It also seems to be related to solar activity in a still unexplained way.

The opportunity of obtaining all this important information and similar data causes scientists to prepare in advance for and await eagerly each eclipse. In addition, thousands of amateurs all over the world frequently participate in observational programs and have provided many supplementary data for a variety of studies, including those mentioned above.

SOLAR ECLIPSES on the Moon

The possibility of observing eclipses from the moon offers a number of unique advantages for studies heretofore not possible. The greatest advantage is that observations of SOLAR ECLIPSES caused by the passage of the earth between sun and moon are of much longer duration for an observer on the moon. Furthermore, they can be observed from wide areas of the moon's surface. Since the moon has no appreciable atmosphere, the usual atmospheric interference with observation is missing.

Viewed from the moon during a SOLAR ECLIPSE, the earth can theoretically be expected to be surrounded by refraction images of the sun, and by a narrow, bright fringe caused by diffusion of light in the earth's atmosphere. (Recall the Mercury astronaut observations of the terrestrial horizon.) Near the center of the shadow, and in the blue part of the spectrum, this parasitic illumination by the terrestrial atmosphere should be quite noticeable.

In addition to the studies applicable to solar eclipses observed from earth, observations from the moon will provide data on the geocorona, the outermost regions of the earth's atmosphere. Precise timing of the passage of the shadow at the observation site, and measurements of the shadow intensity, cosmic ray activity, and surface and soil temperature can be performed on the spot.

TERRESTRIAL ECLIPSES on the Moon

An astronaut on the moon will observe a TERRESTRIAL ECLIPSE as the passing of a circular shadow disk, surrounded by a lighter penumbra, over the surface of the earth. This will be a new experience, and it is difficult to foresee exactly what those data may reveal. Some of this is discussed below.

Simultaneous Observations

With reference to Fig. 1, recall that we on earth observe an eclipse of the moon while an astronaut on the moon is experiencing a SOLAR ECLIPSE. Analogously, limited areas on earth experience a solar eclipse while a TERRESTRIAL ECLIPSE is occurring on the moon. Uniquely important results can therefore be expected to come from simultaneous observations of these phenomena. During eclipses on the moon, an astronaut (perhaps supplemented by a manned spacecraft in orbit around the earth) could give us unprecedentedly comprehensive eclipse data. Among the desired supplementary data are timings of the shadow passage, weather information along the terminator, visual appearance of the moon's surface, density of the shadows, appearance and activity of sun's disk and solar corona, reflectivity of the moon's surface, albedo of earth, and many more.

Instrumentation

It cannot be overemphasized that lunar astronauts will need exceedingly simple instrumentation. Until later years when scientific results will enable specification of more sophisticated equipment, all the studies mentioned above can be performed with photographic equipment with various filters, thermometers, a simple telescope, a stop watch, a geiger counter, etc.

Eventually, one can foresee demands for much more complicated equipment, even radio telescopes and cosmic ray monitors. But these, one should remember, could be landed in advance by unmanned spacecraft, and later activated or guided by astronauts.

Despite the seeming simplicity of the desired observations, having them performed by unmanned instruments would be a formidable and very complicated requirement. Perhaps in no other aspect of the initial Apollo program are man's unique abilities so necessary for the performance of scientific studies impossible from the earth.

Tables 1 and 2 are listings of suggested initial observations to be performed during a SOLAR ECLIPSE and during a TERRESTRIAL ECLIPSE, respectively. The listing is not exhaustive, but is indicative of the type of simple experiment suitable for early Apollo flights.

Table 1

Proposed Initial Experiments During the Occurrence of a SOLAR ECLIPSE on the Moon

Observing Site	Observational Program
On the Moon	Color photographs of sun Time-lapse movies of solar corona Timing of eclipse progress Filter photography of sun and solar corona Timing of shadow passage at observing site Soil temperature at observing site Cosmic-ray intensity at observing site Color photography of terrain of observing site (shadow intensity)
On Earth	Standard professional observations for occurrence of lunar eclipse (astronomy, meteorology, lunar physics) Amateur astronomer participation (photography, eclipse timing, shadow brightness, crater timings) Public participation (local weather information, photography, timings)
Aboard Spacecraft (in Earth Orbit)	Photography of Moon Photometry of albedo Weather formations along terminator

Table 2

Proposed Initial Experiments During the Occurrence of a TERRESTRIAL ECLIPSE on the Moon

Observing Site	Observational Program
On the Moon	Photography of earth Time-lapse movies of shadow progression Timing of shadow transit over earth Albedo observations Radio reception studies
On Earth	Standard professional observations for occurrence of solar eclipse (astronomy, solar physics, ionospheric physics, radio astronomy) Amateur astronomer participation (photography, eclipse timing) Public participation (solar photography, timing, terrain photography, radio reception, air temperature measurements)
Aboard Spacecraft (in Earth Orbit)	Photography of sun and solar corona Radio transmission and reception studies Photography of shadow transit on earth Cosmic-ray experiments

LONG-TERM ASPECTS

The conduct of eclipse observations from the moon by astronauts should be considered as one portion of a comprehensive program of related observations. In this context, it has already been shown that the suggested initial observations should be carried out jointly with complementary observations being performed on earth, and from manned earth-circling spacecraft. This preliminary phase can be expected to provide scientific pay-offs primarily in solar physics and geophysics.

A second phase can be foreseen, after the initial results and experience clarify the course that a long-term mission program should take. If thought of as part of the Apollo-follow-on activities, the requirements can be split into two avenues -- on the moon and on a space station. First, the observing capabilities on the moon might be expanded by providing more sophisticated, second-generation instrumentation. This should include astronomical equipment to permit photometry and spectroscopy, and perhaps radio astronomy. Another, parallel program phase should provide for scientifically analogous equipment aboard a manned space station in orbit around earth. During this time period, it may also become technically feasible for cis-lunar flights, in the space between earth and moon, to follow trajectories which will result in temporary eclipses of the sun, earth, and moon for on-board observers. Throughout this second phase, emphasis should again be placed on opportunities for coordinated, simultaneous observations. In addition to scientific results valuable for solar physics and geophysics, this program phase will be able to provide important data for studies in astronomy, meteorology, interplanetary physics, and relativity theory.

A third phase of the program would become desirable in the context of manned interplanetary flights. Although the characteristics of the earth-moon system are such as to make this regime the most desirable for the scientific objectives of eclipse research, interplanetary flight will provide opportunities for observing occultations of stars by planets, for example, or transits of planets in front of the sun (a very rare occurrence for us to see from earth). Because of the small sizes of the moons of Mars, and the absence of any moons around Venus, in situ exploration of these planets will not provide directly any increased payoff from eclipse observations, as against routine astronomical observations. However, discoveries made during the earlier phases of the suggested eclipse observation program may open desirable objectives not foreseen at this time.

IV. TECHNICAL PROBLEMS

TIME RESTRICTIONS

Eclipses follow a precise time schedule. Though restrictions on operational timing are thus severe with respect to the day of an eclipse, they are much less limited than on earth with regard to favorable observing locations and hours of occurrence.

Table 3 below is a list of the eclipses scheduled to occur during the next few years. It is taken from the classical Canon of Eclipses by von Oppolzer.[5] Note that solar and lunar eclipses are separated by approximately a fortnight. Note also that no SOLAR ECLIPSE is listed to occur on the moon between October 1968 and February 1970.

Table 3

Eclipse Schedule

SOLAR ECLIPSE on Moon (Lunar Eclipse on Earth)			TERRESTRIAL ECLIPSE on Moon (Solar Eclipse on Earth)		
13 April	1968	*	28 March	1968	
6 October	1968	*	22 September	1968	*
21 February	1970		18 March	1969	
10 February	1971	*	11 September	1969	
6 August	1971	*	7 March	1970	*
30 January	1972	*	31 August	1970	
26 July	1972		25 February	1971	
10 December	1973		22 July	1971	
4 June	1974		20 August	1971	
29 November	1974	*	16 June	1972	
25 May	1975	*	10 July	1972	*

*Total

Further ephemeris-type calculations are needed to provide such additional information as the following: precise times and paths of the eclipses as viewed from the moon; favorable locations for observers on the moon; potential tangential occurrences not listed in Table 3, and the degree of such eclipses on the moon; potential stellar and planetary eclipses and transits for cis-lunar and interplanetary trajectories.

SYSTEM OPERATIONS

Operational restrictions are primarily those of timing discussed above. Scientifically, the most desirable observations are those of eclipses of the sun by earth (i.e., SOLAR ECLIPSES on the moon) -- especially total ones.

The simple instrumentation required for the initial program phase was discussed in Section III. Provision has to be made, however, for such instruments as cameras to be easily operated by astronauts in space-suits. Instruments for radio-astronomical observations during later Apollo flights could be landed in advance by unmanned spacecraft.

Pre-training of astronauts would be desirable and should include about five instructional lectures on the basic scientific principles involved, training in the use of instrumentation, and the observing of eclipses from ground or from aircraft during the years prior to the missions.

V. SCIENTIFIC COMMUNITY AND GENERAL PUBLIC

EXPECTED REACTIONS

There is a well-known dichotomy among the scientific community with regard to the value of manned space exploration as against exploration by unmanned, instrumented spacecraft. The proposition of declaring eclipse observations as one of the major scientific objectives of the Apollo program can be expected to receive a predominantly favorable reaction.

First, it should be emphasized that there is nothing new about a suggestion to observe eclipses from the moon. In fact, basic eclipse theory uses a mathematical approach along these lines.[2] While not many scientists are acquainted with the applicable theories and the current state of knowledge in the field, eclipses per se are not an abstruse phenomenon. Thus, scientists of many disciplines are at least aware of the great scientific value of such observations, if not all the detailed applications in astronomy, solar physics, geophysics, meteorology, and relativity theory. This contrasts strongly with the limited, specialized interest in geological studies of the lunar surface, for example.

Secondly, it has been pointed out that observing techniques on the moon require rather simple instrumentation that can easily be used by astronauts with little pre-training. Conducting these observations by means of automatic instrumentation, on the other hand, would represent a formidable task, probably beyond our technical abilities for years. Furthermore, it would so increase the complexity and weight demands for automatic guiding and programming equipment that manned operation seems economically mandatory.

It does not appear too optimistic to expect that, once these ideas penetrate the scientific community, the proposed program may become "the obvious thing to do for astronauts on the moon."

PUBLIC PARTICIPATION

An additional aspect of the proposed program cannot be underemphasized. Lunar and solar eclipses are one of the very few scientific phenomena which represent something understandable to the layman. Eclipses are something that many people have seen themselves, read about in the newspapers, seen pictured in magazines; they are not something strange that only scientists talk about.

In a call for international simultaneous observations by laymen, it must not be expected that the general public can contribute many important scientific data. These can be expected to come from thousands of amateur astronomers over the world. On the other hand, some simple participation, such as observations of local cloudiness or timings of the eclipse could be useful.

More important, this asking for help through performance of simple observations by the general public while the astronaut is doing similar observations on the moon, should create a feeling of personal participation in the Apollo program. No doubt the press and communication media would provide for general awareness. Of importance for worldwide coverage would be the performance of such observations on an international scale. Professional participation could be arranged through the National Academy of Sciences, and governmental channels could be used to enlist the population of other countries.

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